US DEPARTMENT OF ENERGY
COOPERATIVE AGREEMENT NO.
DE-FC02-00CH11053

FUEL FLEXIBLE, ULTRALOW-EMISSIONS COMBUSTION SYSTEM FOR INDUSTRIAL GAS TURBINES

Peer Review - March 2002

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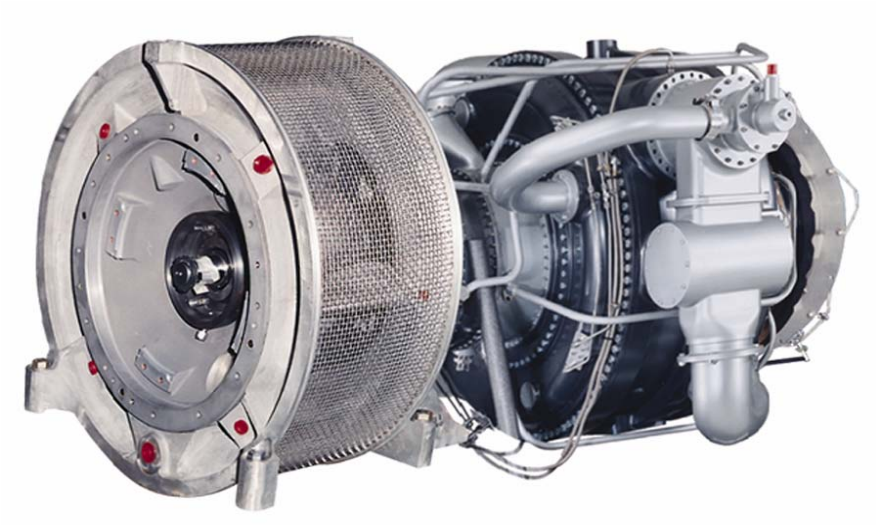
FUEL FLEXIBLE, ULTRA-LOW EMISSIONS COMBUSTION SYSTEM FOR INDUSTRIAL GAS TURBINES

Technical Approach

- rich/catalytic/lean burn (RCL™) combustion system
- fully air-staged for accurate flame temperature control
- fuel flexible - gas & liquid
- real time emissions sensing for closed loop air staging control
- targeted for the ASE50DLE 3.9 MW industrial engine (11:1 PR)



ASE50DLE engine

FUEL FLEXIBLE, ULTRA-LOW EMISSIONS COMBUSTION SYSTEM FOR INDUSTRIAL GAS TURBINES

Main Program Objectives & Targets

Program Objective	DOE Objective
Technology demonstration and risk reduction on a low NOx catalytic combustion system for industrial gas turbines	Encourages adoption and use of ultra-low emissions technology
Target NOx levels below 5 ppm on natural gas	NOx < 5 ppm on natural gas
Catalyst system to be capable of running on both natural gas and Diesel fuels	Technology transition to alternate and back-up fuels and reduce NOx emissions on these fuels
Catalytic combustion system to be retrofitable into the Honeywell ASE50DLE industrial engine	Encourages adoption and use of ultra-low emissions technology
Develop direct NO/CO emissions sensing system to prototype level	NOx < 5 ppm Adaptability to alternate and back-up fuels

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Program Organization - Collaboration

- Honeywell is lead contractor - responsible for integration of catalyst system into engine
- Precision Combustion Inc. (PCI) - responsible for catalyst module development, testing & definition
- Texas A&M University - responsible for development of prototype, real-time emission sensing system
- Vericor Power Systems - partial funding & voice of the customer

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Program Approach - Phase 1 (Concept Study)

Subtask 1.1 - Sub-Scale Catalyst Development (PCI)

- design & optimize catalyst for engine operating conditions, pressure drop, and emissions on natural gas
- sub-scale catalyst test program based on natural gas and Diesel fuel, testing to include an alternate fuel
- define catalyst modules for ASE50DLE application

Subtask 1.2 - Combustor Preliminary Design and Development (Honeywell/PCI)

- preliminary design of a dual fuel catalytic combustion system for the ASE50DLE engine
- define the form, fit, and function of a combustion system to integrate the catalyst module into the ASE50DLE engine

Subtask 1.3 - Emissions Sensor Breadboard Development (Texas A&M University)

- develop novel, diode-laser-based, real-time NO/CO emissions sensing system to prototype level, aimed at closed loop control of air-staging valves
- engine demonstration of prototype at Honeywell

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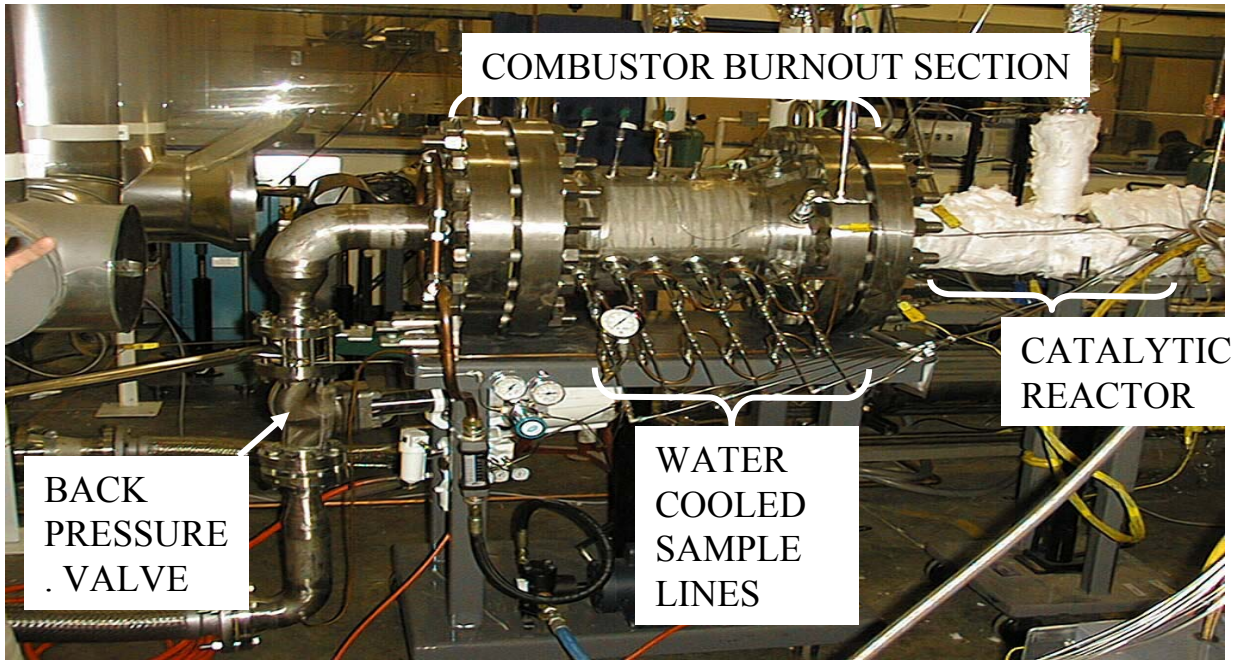
Subtask 1.1 - Sub-scale Catalyst Development (PCI)



RCL™ for ASE50DLE single digit emissions and operability developed and designed.

Stable, lean combustion downstream of catalyst at low firing temperatures (1300°C/2400°F) achieved.

Steam vaporization of Diesel selected over preheater approach for reduced risk & system simplicity (cogeneration)

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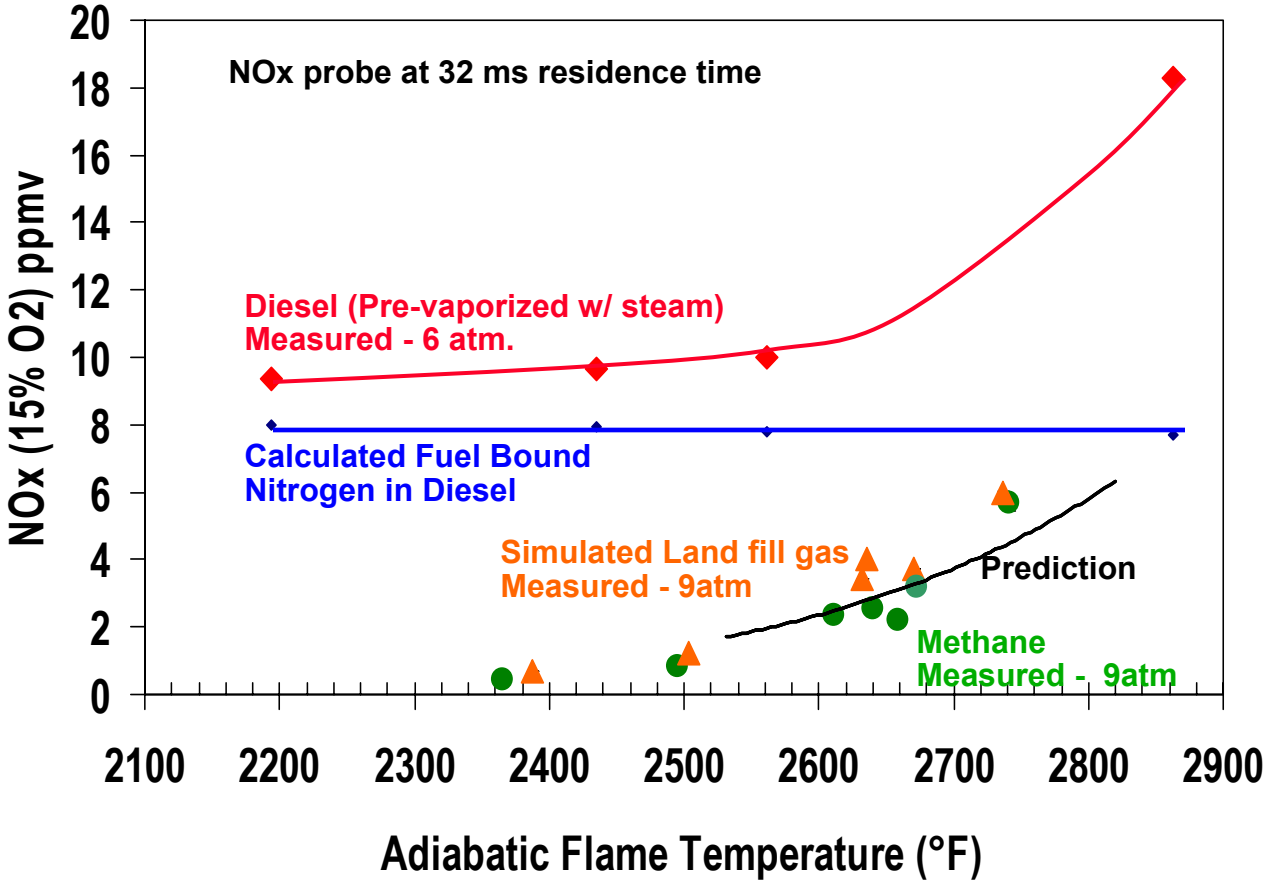
Subtask 1.1 - Sub-scale Catalyst Development (PCI)



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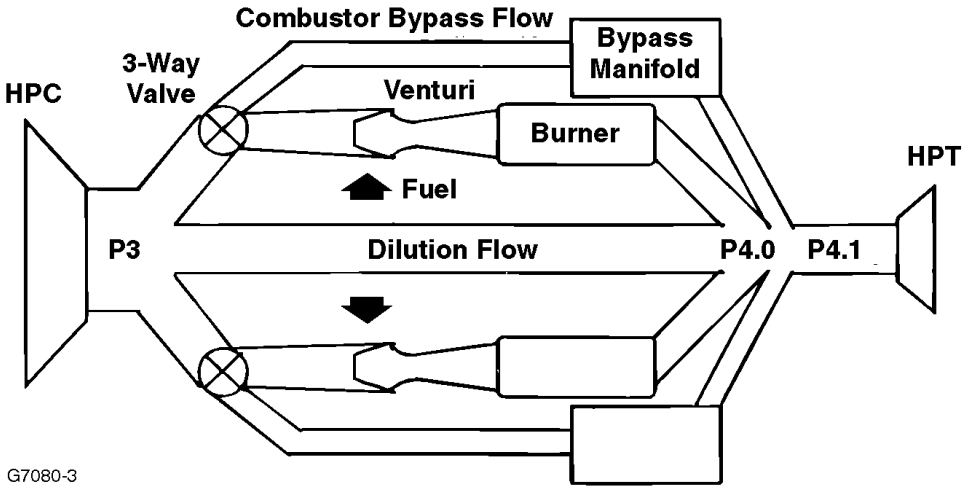
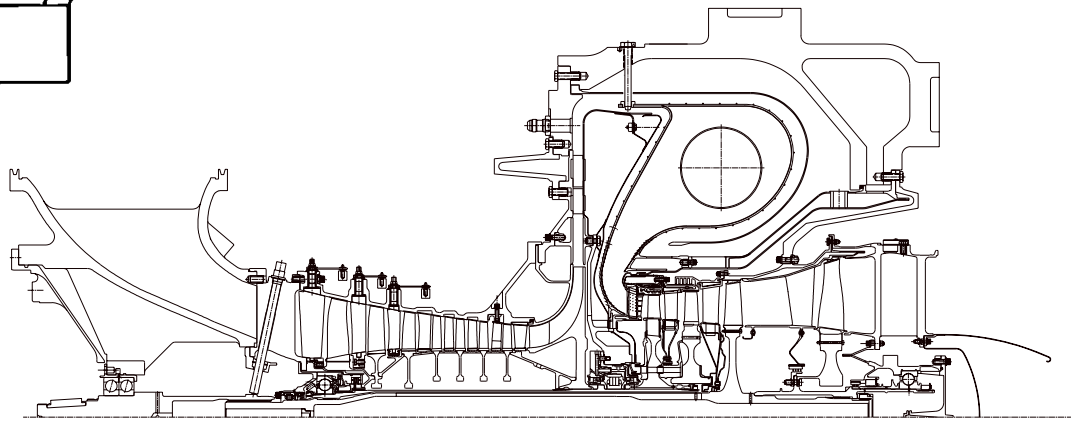
Subtask 1.2 - Combustor Preliminary Design (Honeywell/PCI)
Honeywell Air Staging Concept



- Air staging provides constant flame fuel/air ratio over entire operating range
- Air staging valves maintain constant pressure drop at all positions
- Allows closed loop control of flame temperature using emissions feedback

- Independent control of each premixer possible
- Automatic flashback control



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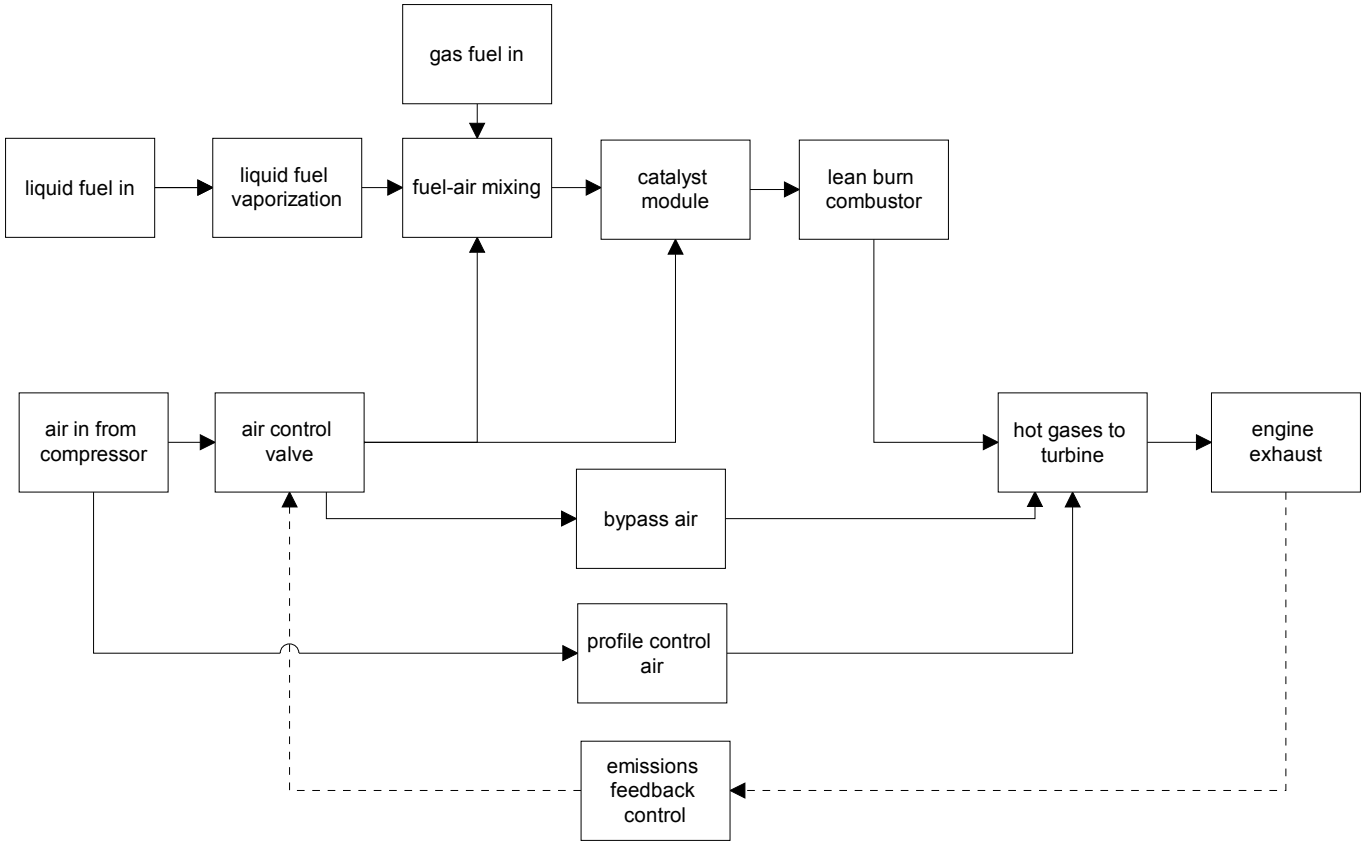
Subtask 1.2 - Combustor Preliminary Design (Honeywell/PCI)

Schematic of dual fuel catalyst combustion system



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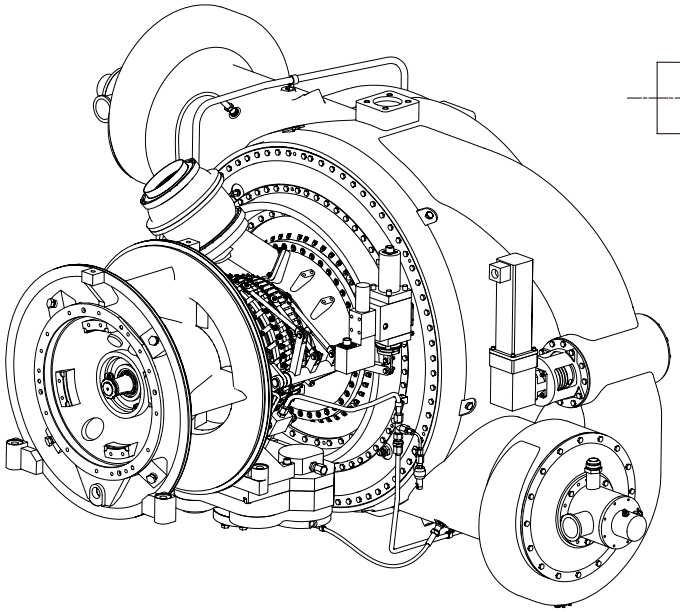
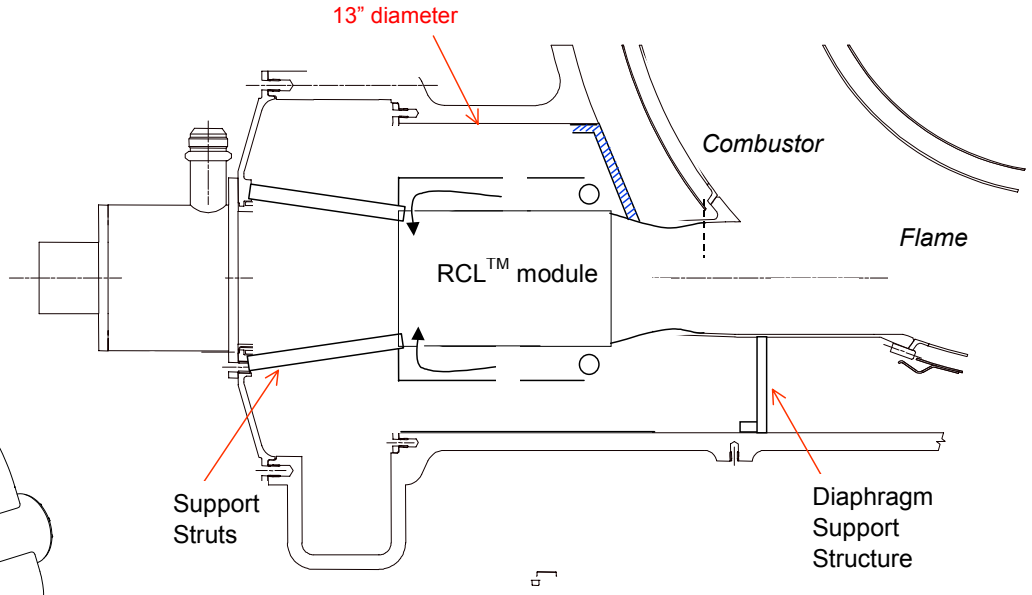
Subtask 1.2 - Combustor Preliminary Design (Honeywell/PCI)

Integration of RCL™ modules into ASE50DLE engine





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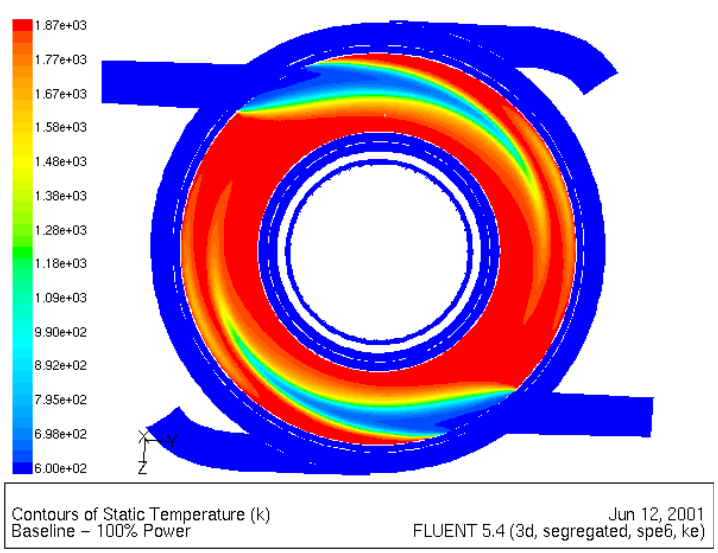
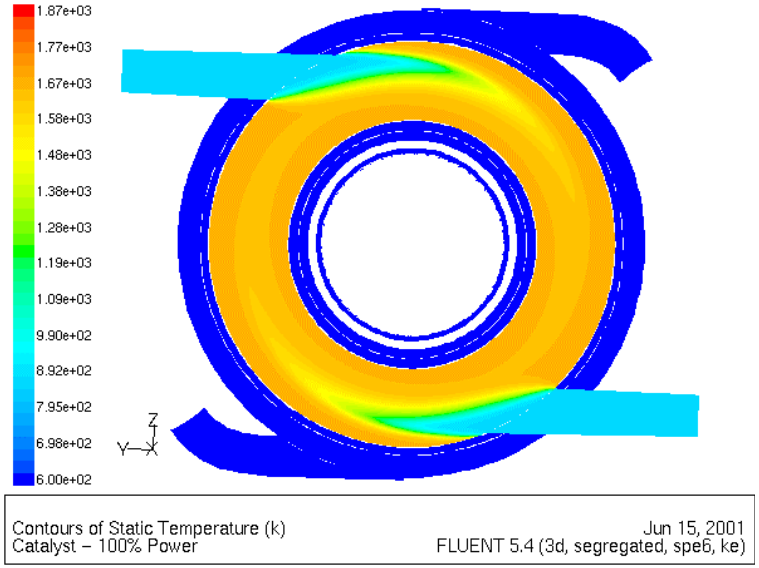
Subtask 1.2 - Combustor Preliminary Design (Honeywell/PCI)

Integration of RCL™ into ASE50DLE engine - predicted combustor temperature distribution

lean premixed baseline



catalytic combustion



Lower flame temperatures reduce NOx, preheating lowers CO

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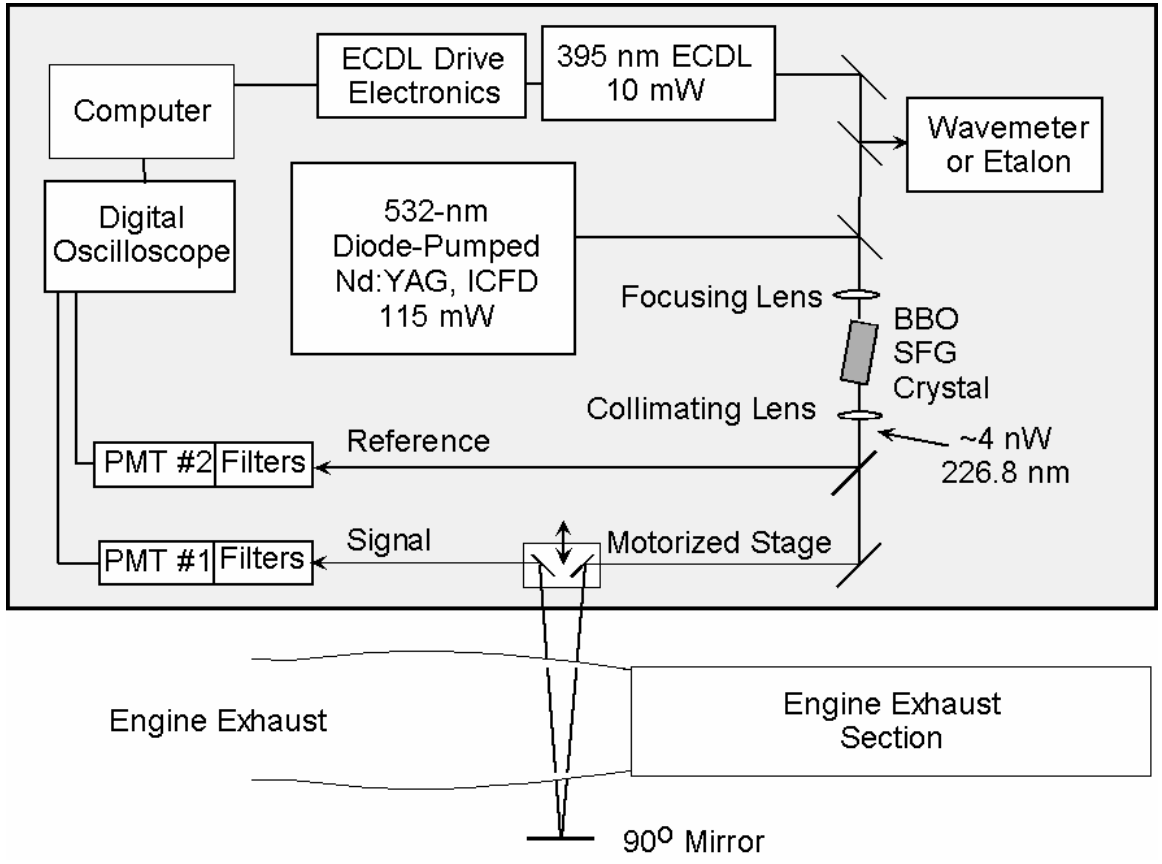
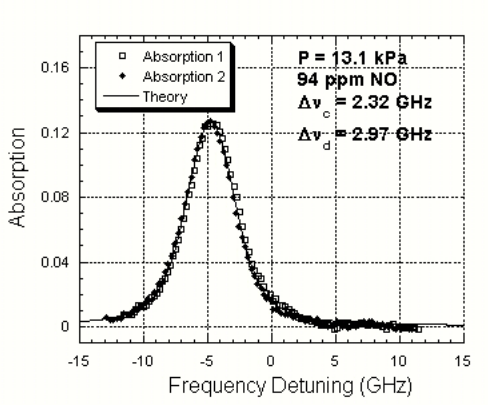
Subtask 1.3 - Emissions Sensor Development (Texas A&M University)

Schematic of NO Exhaust Emissions Sensing System



NO Spectrum from 0.30 m Gas Cell



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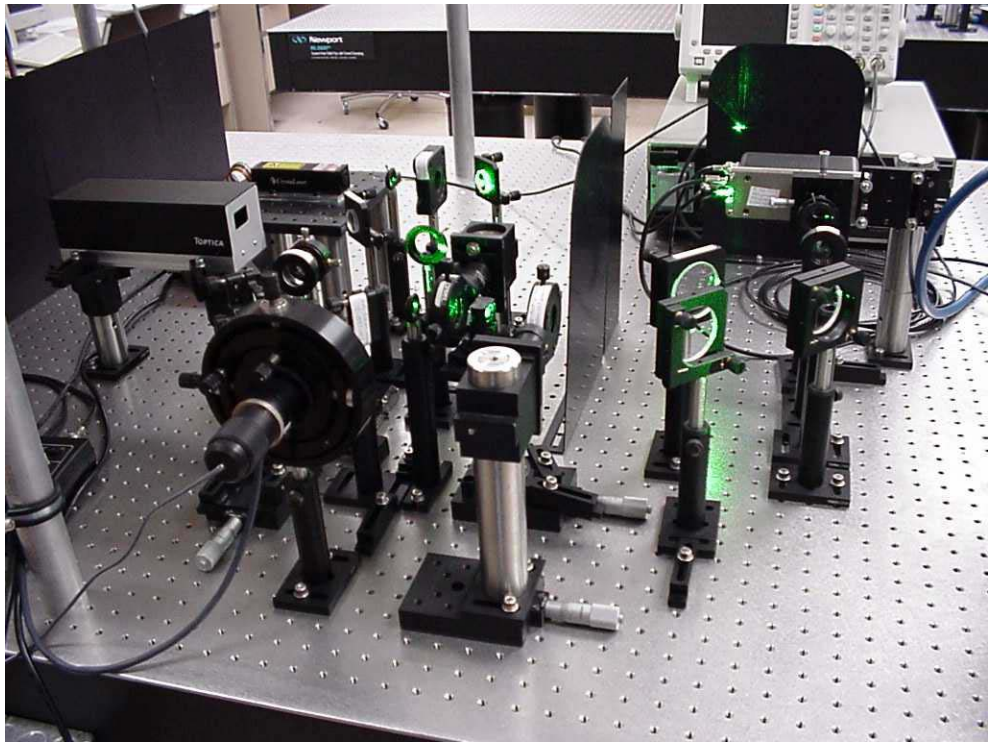
Subtask 1.3 - Emissions Sensor Development (Texas A&M University)

NO Sensor Operating at Texas A&M University



Novel NO sensor demonstrated at Texas A&M University with sub-ppm sensitivity for a 1 m path length

Sum frequency mixing of visible lasers used to generate UV light

Ruggedized, compact version of the sensor is being developed on a 2'x4' breadboard

Engine test at Honeywell in May, 2002

CO sensor at 4.5 μm has also been developed, initial measurements in progress

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Summary of Technical Progress/Status

Subtask 1.1 - Sub-Scale Catalyst Development (PCI)

- Conversion rate testing completed on natural gas, Diesel and simulated landfill gas - catalyst design for combustion tests defined
- emissions tests on methane, Diesel and simulated landfill gas completed
    - NOx < 5ppm on methane and landfill gas up to 100% power
    - NOx < 15 ppm on Diesel up to 75% power
- catalyst module sizing for ASE50DLE application defined

Subtask 1.2 - Combustor Preliminary Design (Honeywell/PCI)

- Air staging system calibration completed, first ASE50DLE combustion rig test complete
- casing design to accommodate RCL™ modules completed, integrated into DLE system, hardware available
- method of catalyst integration defined, CFD modeling to optimize inlet air flows in progress

Subtask 1.3 - Emissions Sensor Development (Texas A&M University)

- NO prototype developed and tested using room temperature gas cell, currently packaging for engine test
- Mid-infrared CO system based on difference-frequency mixing has been developed, is currently being tested in laboratory

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Progress towards Objectives

Objective	Status
• NOx levels below 5 ppm on natural gas	• demonstrated
• Catalyst system to be capable of running on both natural gas and Diesel fuel	• demonstrated
• Catalytic combustion system design to be retrofitable into the Honeywell ASE50DLE 3.9 MW industrial engine	• Engine casing designed to suit catalyst, full scale hardware available • Optimization of air inlet in progress
• Develop direct NO/CO emissions sensing system to prototype level	• NO prototype system developed, available for engine test • CO system in progress

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Future Work

Short term, 2002 (included in present program)

- complete CFD modeling study of catalyst air inlet region and define configuration to reduce pressure drop and improve air flow distribution
- complete development of the prototype CO system and demonstrate in lab tests
- conduct demonstration of emissions sensing system on engine
- final reporting